UNITED STATES NAVAL OBSERVATORY

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THE NAVAL OBSERVATORY TIME SERVICE

BASIS OF TIME MEASUREMENT

The accepted basis of time measurement is the earth's rotation on its axis. The rate of this rotation is usually considered uniform, although it is doubtless affected by both progressive and other variations. This rotation causes the sun and the stars to appear to cross the sky from east to west. If a person located on the earth's equator, measured the time interval between two successive passages overhead of a very distant star, he would thereby measure the period of the earth's rotation. If he then made similar measurements on the sun instead of a star, he would obtain a result about four minutes longer than before. This difference is due to the earth's motion around the sun, which continuously changes the apparent place of the sun among the stars. The effect is the same as that noted when traveling in an automobile; the near objects appear to move backward when judged by the more distant ones. Thus, during the course of a day the sun appears to move a little to the east among the stars, so that the earth must rotate on its axis through more than 360° in order to bring the sun overhead again. Even if the earth did not rotate at all on its own axis the sun would rise and set once during the year, because of the earth's journey around it. The stars, however, are not within the earth's orbit. Since they are generally more than a

million times as distant as the sun, their apparent positions are only very slightly affected by the earth's orbital motion. The apparent positions of the stars in the sky are commonly reckoned with reference to an imaginary point called the *vernal equinox*, which is the intersection of the celestial equator and the ecliptic. The sun is at the vernal equinox at the beginning of spring, when it passes over the earth's equator on its journey northward. The period of the earth's rotation measured with respect to the vernal equinox is called a *sidereal day*, although it might better be named an *apparent equinoctial day*. The period with respect to the sun is called an *apparent solar day*. Unfortunately both the sun and the equinox move at variable rates among the stars, and consequently the apparent solar and sidereal days are of variable length. In order to overcome this irregularity, mean time has been devised. *Mean solar time*, which is generally used in ordinary life, is sometimes ahead of and sometimes behind apparent solar time, but on the average it is the same. The difference between these two kinds of time is called the *equation of time*. Its maximum value is a little over sixteen minutes. The difference between apparent equinoctial (sidereal) time and mean equinoctial (sometimes called uniform sidereal) time is due to the nutation or nodding of the earth's axis. Its greatest value is only a little over a second, and its greatest daily change is a little more than a hundredth of a second. Because this difference is so small, sidereal time has generally been used by astronomers. Some observatories, including the Naval Observatory, now employ mean equinoctial time in computing the rates of precision clocks. A more detailed explanation of the various kinds of time referred to above can be obtained from textbooks on astronomy.

STANDARD TIME

Since the sun does not rise and set in different parts of the world at the same time, it is evident that mean solar time varies from place to place. In order to reduce confusion, standard time zones have been adopted. All the places in each zone use one uniform time which generally differs from the times of the adjoining zones by one hour, and by an integral number of hours from *Universal Time*, which is the mean solar time based on the prime meridian of Greenwich. Universal Time has been referred to as Greenwich Civil Time in the United States and as Greenwich Mean Time in Great Britain. The continental United States, excepting Alaska, is divided into four time zones, namely, Eastern, Central, Mountain and Pacific. Eastern Standard Time is the same as the local mean solar time of the 75th meridian west of Greenwich; it is five hours less advanced than Universal Time. Eastern Daylight Saving Time is four hours less advanced than Universal Time. Pacific Standard Time is the local time of the 120th meridian; it is eight hours less advanced, and Pacific Daylight Saving Time is seven hours less advanced than Universal Time. The Naval Observatory time signal which is sent out at four hours, Universal Time, serves as an 11:00 p.m. signal according to

Eastern Standard Time, as a 10:00 p.m. signal according to Central Standard Time, and so forth. A list of corresponding times may be found in the section on *Signal Hours*. Since the object of the time zones is mainly one of convenience, the boundaries between the zones have been placed where they will be the source of the least inconvenience, rather than along exact meridians. For instance, if the lines were straight the people in one part of a small town might be using different time from their neighbors, and the railroad trains might have to make time changes at inconvenient points rather than at terminals. The Interstate Commerce Commission holds hearings concerning the placing of these division lines, and all inquiries on the subject should be addressed to that Commission. The Hydrographic Office, U. S. Navy Department, Washington 25, D. C., sells a chart showing the time zones of the world. The chart is Number 5192 and the price is seventy cents ($.70). The Superintendent of Documents, U. S. Government Printing Office, Washington, 25, D. C., sells a map showing the standard time zones in the United States. The map is designated as Miscellaneous Publication No. 190 of the National Bureau of Standards, and the price is fifteen cents ($.15).

TIME DETERMINATION

In order to determine time with high precision, it is necessary to observe stars, or other celestial objects, with a telescope. Such observations are most conveniently and accurately made when the stars are passing over the meridian at the place of observation. The meridian is an imaginary line in the sky, passing through the zenith and the north and south points. The most commonly used instruments for time determination at fixed stations are called meridian transit telescopes. They are pivoted so that they may be pointed anywhere along the meridian, but not elsewhere. The observations are usually made visually, and the times of transit are recorded by a mechanism which is either operated or regulated by the observer.

At the Naval Observatory an instrument called the photographic zenith tube is used for time determination. This instrument is rigidly fixed in a vertical position, and therefore cannot photograph any objects except those which pass very near the zenith. At the lower end of the tube is a basin filled with mercury. The light from a star passes through a lens at the upper end of the instrument, continues down through the tube, is reflected from the mercury surface, and comes to focus on a small photographic plate located just under the lens. The location of the plate and the curves of the lens are such that the lens and plate may be tilted as a unit, through a small angle, without sensibly altering the position of the image on the plate. If the plate and the lens are rotated through 180°, then the distance on the plate between the images of the star, before and after reversal, corresponds to twice the zenith distance of the star. Were it possible to take both photographs in the same instant, when a star was exactly in the zenith, the two images would coincide and the time of meridian transit would be the time when the photograph

was taken. In actual practice the plate is driven from west to east so as to keep pace with the motion of the star's image, and the clock time at which the plate is in certain positions is automatically recorded. The images obtained before and after reversal do not coincide, but by measurement of the distances of the images it is possible to determine the positions of the stars during exposure, and to deduce the times of transit. Recently a second photographic zenith tube station has been located at Richmond, Florida. With the aid of this second instrument of improved design, and the advantages of more favorable latitude and a greater percentage of clear nights, it is expected that greater accuracy in time determination will be possible.

TIME CALCULATIONS

By observing the time of meridian transit of the sun, the time of local apparent solar noon is ascertained without further calculations. Sun observations are not so precise as those of stars, owing to the size of the sun's disk, and the unsteadiness of the atmosphere at mid-day. It is possible to observe a number of stars during one night, thereby increasing accuracy. To make the star observations useful, the positions of the stars in the sky, as measured from the vernal equinox, must be known. As the relative motions of the sun and earth fix the positions of the equinox, solar observations are a necessity. Observations of the sun and the stars regularly over a period of several years, show their relation very accurately. The results of this long series of observations are utilized in making the calculations for the reduction of a single night's time observations. The Naval Observatory maintains a regular program of observations of the sun, stars, and planets. It also publishes annually "The American Ephemeris and Nautical Almanac," giving the computed positions and motions of the more important celestial objects as indicated from the results of past observations. By use of data contained in these volumes, the correct sidereal and mean solar time of the star transits are derived.

STANDARD CLOCKS

As previously explained, during the time when each star is being photographed by the zenith tube, a chronograph automatically records electric signals produced by the movement of the plate carriage in the telescope, and also signals produced by the ticking of one of the standard clocks. Thus the clock time of the star's transit is determined within a small fraction of a second. By comparing these clock times with the theoretical times of star transit, computed as previously indicated, the clock error is determined.

The standard clocks now in use are quartz-crystal controlled. In this type of clock a small quartz crystal, which is enclosed in a vacuum tube and kept in a constant-temperature oven, takes the place of a pendulum or balance wheel in other types of clocks. The crystal oscillates 100,000 times a second and controls

an electric current which is used to drive a synchronous motor clock movement. The function of the clock movement is to count the vibrations of the crystal and show the elapsed time interval. Several quartz-crystal clocks are used as standards. They are all checked by reference to the astronomical observations, and their errors and rates are determined. During periods of a few days the variation in the daily rates of these clocks does not ordinarily exceed one thousandth of a second.

TIME SIGNALS

Time signals based on Naval Observatory time determinations are sent out by the stations listed below:

NSS = U. S. Naval Radio Station, Annapolis, Maryland
NPG = U. S. Naval Radio Station, Mare Island, California
NPM = U. S. Naval Radio Station, Pearl Harbor, Territory of Hawaii
NBA = U. S. Naval Radio Station, Balboa, Canal Zone
WWV = Standard Frequency Station of National Bureau of Standards, Beltsville, Maryland
WWVH = Standard Frequency Station of National Bureau of Standards, Maui, Territory of Hawaii

The signals sent out by naval radio stations are all transmitted on continuous waves, and can only be heard with receivers which are suited to code reception. These stations transmit time signals during the last five minutes of certain hours as shown by the schedule. Signals (dashes) are transmitted on each second of the five minute period, except that no signals are sent on the 29th second of any minute or on certain seconds at the ends of the minutes, as shown by the following diagram. The dashes indicate the seconds on which signals are transmitted. The seconds marked "60" are the zero seconds of the following minutes. The signal at the end of the 5 minute period, i.e. on the beginning of the hour (shown as 59 minutes 60 seconds below) is much longer than the others. In all cases the beginning of each dash indicates the beginning of a second. The ends of the dashes are without significance. Signals are transmitted on all the seconds not shown below (1 to 49, inclusive) except that there is no signal on the 29th second of any minute, as stated above.

Minutes	Seconds										
	50	51	52	53	54	55	56	57	58	59	60
55	–		–	–	–	–					–
56	–	–		–	–	–					–
57	–	–	–		–	–					–
58	–	–	–	–		–					–
59	–										——

The stations listed below transmit time signals for five-minute periods ending on the hours listed, according to Universal Time. For conversion into standard zone time refer to section on *Signal Hours*. Under the call letters of each radio station are listed the frequencies in kilocycles used in transmitting via these stations. 1000 kilocycles equal 1 megacycle. For example: 4390 kc. = 4.39 megacycles.

Frequencies and times of transmission subject to change without notice.

Universal Time (Greenwich Civil Time)	NSS	NSS	NSS	NSS	NSS	NPG	NPM	NPM	NBA
0^h	122	4390	9425	12630	17000	115			
2	122	4390	9425	12630	17000				
3						Note 1			
4	122	4390	9425	12630	17000		Note 2	17370	
5									Note 3
6	122	4390	9425	12630	17000				
8	122	4390	9425	12630	17000	Note 1			
10	122	4390	9425	12630	17000				
12	122	4390	9425	12630	17000				
14	122	4390	9425	12630	17000				
15						Note 1			
16	122	4390	9425	12630	17000		Note 2		
17						115			Note 3
18	122	4390	9425	12630	17000				
20	122	4390	9425	12630	17000	115	Note 2	17370	
22	122	4390	9425	12630	17000				

Note 1: 115, 9255, and 12540 kc.
Note 2: 113, 4525, 9050, 13575, 21990 kc.
Note 3: 148, 5005, 11080 kc.

Stations WWV and WWVH transmit standard frequencies and superimposed time signals using several carrier frequencies as listed below. The transmissions are made using modulated waves and may therefore be heard with ordinary radiophone receivers. A pulse 0.005 second in duration is transmitted on every second, except the 59th second of each minute. These pulses consist of five cycles of a 1000-cycle audio note, and are heard as clicks when listening to the broadcast. They are superimposed on an audio frequency. At precisely one minute before the hour and at every multiple of five minutes thereafter the audio frequency is interrupted for an interval of exactly one minute, for the purpose of making announcements. The Universal Time when the audio tone will be resumed is transmitted in International Morse Code, using four digits on the twenty-four hour system, and starting with 0000 at 0^h Universal Time. The first two digits give the hour and the

last two give the minutes. Station WWV also makes a voice announcement of the hour and minutes in Eastern Standard Time. The time signal beats continue during the interruptions.

Station WWV transmits time signals continuously day and night. Station WWVH is interrupted for periods of approximately four minutes immediately after each hour and half hour, and for periods of approximately forty minutes beginning at 0700 and 1900 U. T.

WWV	WWVH
Radio Frequency	Radio Frequency
2,500 kc.	
5,000	5,000 kc.
10,000	10,000
15,000	15,000
20,000	
25,000	
30,000	
35,000	

During the first four minutes of each hour a modulated frequency of 600 cycles per second is transmitted. This is followed by a transmission of 440 cycles during the fifth to the ninth minute. These frequencies continue to alternate during the remainder of the hour.

Further information as to the standard frequency broadcasts or of the Radio Propagation Disturbance notices may be obtained by addressing the Central Radio Propagation Laboratory, National Bureau of Standards, Washington 25, D. C.

SIGNAL HOURS

For conversion of Universal Time into standard time and daylight saving time in the United States the following table is provided:

Universal Time (Greenwich Civil Time)	Eastern Daylight	Eastern Standard or Central Daylight	Central Standard or Mountain Daylight	Mountain Standard or Pacific Daylight	Pacific Standard
0^h	8:00 p.m.	7:00 p.m.	6:00 p.m.	5:00 p.m.	4:00 p.m.
2	10:00 p.m.	9:00 p.m.	8:00 p.m.	7:00 p.m.	6:00 p.m.
3	11:00 p.m.	10:00 p.m.	9:00 p.m.	8:00 p.m.	7:00 p.m.
4	Midnight	11:00 p.m.	10:00 p.m.	9:00 p.m.	8:00 p.m.
5	1:00 a.m.	Midnight	11:00 p.m.	10:00 p.m.	9:00 p.m.
6	2:00 a.m.	1:00 a.m.	Midnight	11:00 p.m.	10:00 p.m.

Universal Time (Greenwich Civil Time)	Eastern Daylight	Eastern Standard or Central Daylight	Central Standard or Mountain Daylight	Mountain Standard or Pacific Daylight	Pacific Standard
8	4:00 a.m.	3:00 a.m.	2:00 a.m.	1:00 a.m.	Midnight
10	6:00 a.m.	5:00 a.m.	4:00 a.m.	3:00 a.m.	2:00 a.m.
12	8:00 a.m.	7:00 a.m.	6:00 a.m.	5:00 a.m.	4:00 a.m.
14	10:00 a.m.	9:00 a.m.	8:00 a.m.	7:00 a.m.	6:00 a.m.
15	11:00 a.m.	10:00 a.m.	9:00 a.m.	8:00 a.m.	7:00 a.m.
16	Noon	11:00 a.m.	10:00 a.m.	9:00 a.m.	8:00 a.m.
17	1:00 p.m.	Noon	11:00 a.m.	10:00 a.m.	9:00 a.m.
18	2:00 p.m.	1:00 p.m.	Noon	11:00 a.m.	10:00 a.m.
20	4:00 p.m.	3:00 p.m.	2:00 p.m.	1:00 p.m.	Noon
22	6:00 p.m.	5:00 p.m.	4:00 p.m.	3:00 p.m.	2:00 p.m.

For instance, if the signals are sent out at 5 hours, Universal Time that is the same as midnight, Eastern Standard Time or 1:00 a.m., Eastern Daylight Time.

SIGNAL RECEPTION

At distances from Washington which do not exceed 800 or 1000 miles, the frequency of 122 kilocycles usually gives the most uniform reception of the Navy frequencies, and requires the least readjustment of the receiver. However, receivers suitable for the reception of 122 kilocycles are difficult to obtain, and many of those in use have been specially constructed. If such receivers are not available or if the distance from Washington is too great, the use of the higher frequencies is recommended. These frequencies may often be heard at great distances, and a number of suitable receivers are on the market. When purchasing such receivers for reception of time signals from the naval radio stations, it is important to remember that they are transmitted on continuous or unmodulated waves. They cannot ordinarily be heard satisfactorily on receivers designed only for radio-phone broadcast reception. Code receivers of the type used by radio telegraph amateurs are recommended. For the reception of stations WWV and WWVH, however, any type of short wave receiver may be used.

ERRORS OF SIGNALS

During the transmission of time signals the Naval Observatory determines the time of reception with respect to one of the quartz-crystal clocks. This is done by means of a device employing a strobotron tube. The correction to the clock is subsequently recomputed using star observations both before and after the signal. The average error of the time signals, as sent on 122 kilocycles, is a little less than one hundredth of a second. However, there are many scientific and technical uses of the time signals which require accuracy of a higher degree. In

order to meet the requirements of such work, the Naval Observatory distributes time signal correction sheets without charge to those who request them. These sheets give the times of the signals, as actually received by radio at the Naval Observatory. Ordinarily these sheets cover all time signals sent from stations NSS, WWV, and as many as possible from other radio stations, including some foreign stations. Times of reception of WWV are given at intervals of twelve hours. Times of reception for other hours may be satisfactorily determined by interpolation. The sheets give only the decimal parts of the second of the times of transmission. Unless otherwise noted it is understood that the error of the signals is only a small fraction of a second. For example, if the time given is 007 it indicates that the signals were $0^{s}.007$ late, while a figure of 984 indicates that they were $0^{s}.016$ early. These sheets are issued to cover periods of one week at a time. After the end of any period there is some delay in sending out the corrections, because it is necessary to take additional star sights, to make the necessary computations, and to mimeograph and mail the sheets. *In doing work requiring the use of these corrections, one important precaution must be observed.* When tuning in the radio time signals, especially when automatic recorders are used, great care must be exercised to insure reception of the beginning of the signal on each second. If the signals are faintly received, the recorder may operate with considerable delay. The obvious remedy is to increase the amplification, so as to insure operation at the beginning of each signal. In the case of the high frequency, or short wave signals on continuous waves, a special difficulty exists. Although the signals on each second begin full strength, there is evidently a slight shift of frequency taking place each time the circuit is keyed. A sharply tuned receiver may appear to receive the signals perfectly, when, as a matter of fact, it is out of tune with the beginning of all the signals, and consequently operating with a delay.

For work of highest precision time transmissions by stations NSS and WWV are to be preferred over those transmitted by other stations.

USE OF TIME SIGNALS

The Naval Observatory time signals were first sent out in order that navigators might check their chronometers before leaving harbor. They have since become the basis of the standard time used in the United States, and are employed generally by navigators at sea in checking chronometers. The Naval Observatory has no special agreement with any telegraph company, but furnishes time signals free to all firms and individuals who provide wires for the purpose to the transmitting room. Many special uses of the signals have arisen. These include longitude determinations for precise surveying and map-making, and gravity determination by means of which minerals and oil are located. Radio monitoring stations use the signals in checking the frequencies of transmitting stations, while seismologists use them in co-ordinating earthquake records. In fact, since

time is one of the dimensions of the physical universe, it is obvious that an accurate knowledge of time is generally necessary to the investigation of physical problems. The Naval Observatory is lending aid to the meeting of many of these needs, and at the same time is continuing to supply time for navigation and commerce.

INQUIRIES

Inquiries should be addressed to the Superintendent of the Naval Observatory, Washington, 25, D. C.

NAVY-DPPO PRNC. WASH. D.C.